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Dragon Warrior Communications Relay Testing Using the K-MAX Helicopter

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14. ABSTRACT

NRL's Communication Systems Branch is developing a communications relay for the Dragon Warrior unmanned aerial vehicle (UAV) that will provide over-the-horizon links for networked data communications through a self-organizing background backbone network using the BAE Systems AN/VRC-99A radio. It will provide wideband TCP/IP services at up to 1 Mbps data rate at ranges up to 50 nmi. Initial flight tests of the equipment were performed using the Kaman Aerospace K-MAX helicopter as a surrogate aircraft. This document reports the results of those tests and the lessons learned.

15. SUBJECT TERMS
Dragon Warrior UAV, Communications relay, AN/VRC-99A, Network radio

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DRAGON WARRIOR COMMUNICATION RELAY TESTING USING THE K-MAX HELICOPTER

1. BACKGROUND

Dragon Warrior Overview

Dragon Warrior is a rotary wing vertical takeoff and landing (VTOL) unmanned air vehicle (UAV) being developed by the Naval Research Laboratory for the Marine Corps Warfighting Laboratory (MCWL). The two payloads planned for Dragon Warrior (DW) are an electro-optical/infrared (EO/IR) imagery/targeting payload, and a communications relay (Comm Relay) payload. The Vehicle Research Section of the Off-Board Countermeasures Branch, Tactical Electronic Warfare Division, is developing the DW airframe; the Sensor Technology Section of the Applied Optics Branch, Optical Sciences Division, is developing the EO/IR payload; and the Integrated Communication Technology Section of the Communication Systems Branch, Information Technology Division, is developing the Comm Relay—all at the Naval Research Laboratory.

The Comm Relay will provide over-the-horizon links for networked data communications through a self-organizing backbone network using the BAE Systems AN/VRC-99A radio. This radio provides a near-term solution for an unmanned aerial communications relay for Marine Expeditionary Units/Amphibious Ready Groups (MEU/ARGs). It provides a wideband TCP/IP data network for dispersed units ashore with reach-back capability to the Battlegroup Network. The Comm Relay will provide TCP/IP services at up to 1 Mbps data rates at ranges up to 50 nmi.

Initial flight tests of both the Comm Relay and EO/IR payloads were made during 30 October 2001 through 9 November 2001 using a Kaman Aerospace Corporation K-MAX "Aerial Truck" as a surrogate for the Dragon Warrior. This report presents the results of the Comm Relay tests. The EO/IR test results are described in NRL/FR/5360--03-10,037.

Purpose of Test

The purpose of this test is to perform initial flight tests of Dragon Warrior Communications Payload, with the K-MAX helicopter serving as the Dragon Warrior surrogate. Tests were conducted to collect communication relay performance data over ranges up to the 50-nmi maximum communication radius under varying terrain conditions, including over seawater. Data were also collected to assess the usability and configuration control requirements in order to develop user guidelines for operation of the DW Comm Relay.

2. TEST DESCRIPTION

Tests were performed to collect performance data under different test conditions to compare clear line-of-sight link quality vs range, foliage and terrain attenuation effects, and overwater propagation effects. RF

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signal level, error rate, throughput, and latency measurements (i.e., packet loss and delay) were collected for all tests. Two ground vehicle nodes and one airborne relay node were used for the tests.

Test Area

The test sites include Kaman Aerospace facilities in Bloomfield, CT; Mountain Meadow Airstrip in Burlington, CT; Talcott Mountain in Avon, CT; Lighthouse Point in New Haven, CT; Short Beach in Bridgeport, CT; Fishers Island, CT; and Block Island, RI. Figure 1 shows the test area and the locations of the various sites.

Fig. 1 — Test area for the Comm Relay tests supported both short-range and long-range tests that included overland and overwater flight paths

Ground-to-ground tests were performed near Kaman Headquarters in Bloomfield, CT; the low-altitude short-range tests were performed in the vicinity of Mountain Meadow Airstrip in Burlington, CT, and the long-range tests were performed in two sorties over central Connecticut and Long Island Sound. Sortie 1 covered the area from Bloomfield, CT, to Lighthouse Point, CT, to Block Island, RI. Sortie 2 was from Bloomfield, CT, to Short Beach, CT, to Fishers Island, CT. No ground station had clear line-of-site to any other ground station. Table 1 lists distances from various test. Aircraft flight pattern and altitudes were based on FAA flight restrictions and weather conditions. Overwater altitude was typically 4500 to 5500 ft. Overland altitude varied from 1500 to 4500 ft.

Table 1 — Distances Between the Various Test Sites Locations

Test Site Locations	Distance (mi)
Talcott Mountain to Mountain Meadow	11
Talcott Mountain to Lighthouse Point	39
Talcott Mountain to Short Beach	48
Talcott Mountain to Block Island	77
Talcott Mountain to Fishers Island	55
Lighthouse Point to Block Island	69
Short Beach to Fishers Island	60

Airborne Equipment Configuration

The airborne equipment for these tests included a VRC-99A network radio and a Panasonic Toughbook laptop computer that served as the Comm Relay Controller. The 28 VDC required by the VRC-99A was provided through the aircraft power distribution system, and a DC-DC converter converted the aircraft power to the 15 VDC required by the laptop. The VRC-99A and the laptop were connected to each other via a 10Base2 Thin Ethernet. The interface to the avionics was through an RS-232 serial interface to the Remote Management System (RMS). The external antenna was connected directly to the radio. Figure 2 is a system diagram of the airborne equipment.

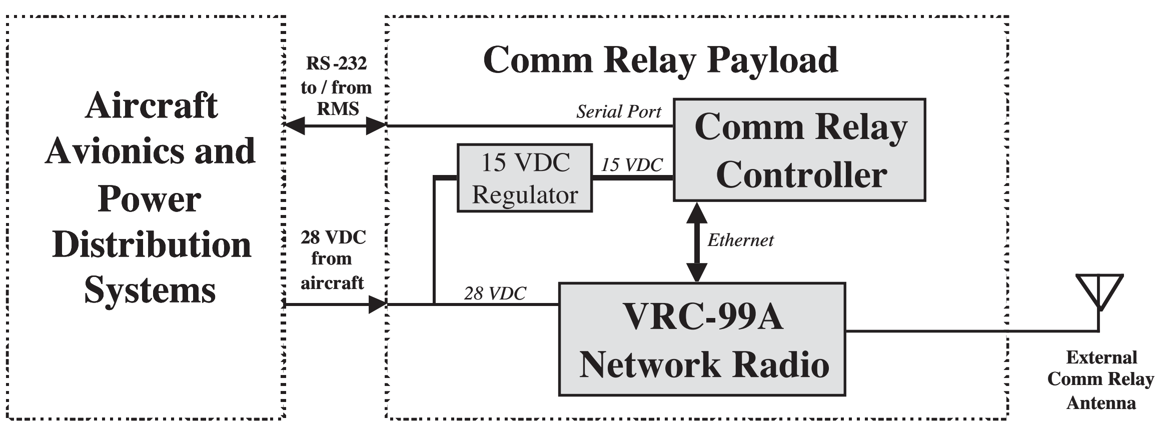

Fig. 2 — Airborne equipment system diagram showing interface of the Comm Relay payload to the aircraft avionics and power, and the components of the payload

The AN/VRC-99A (Fig. 3) is a direct-sequence spread-spectrum network radio that can support data burst rates of 625 Kbps to 10 Mbps in networks of up to 16 radios. It provides a 10Base2 Ethernet interface for a local area network (LAN) and Type 1 encryption of user data. It provides 10 W of output power in the 1308 to 1484 MHz frequency range.

Fig. 3 — The AN/VRC 99A is the network radio for Comm Relay

Figure 4 shows the layout of the airborne Comm Relay equipment in the payload bay, with the VRC-99A radio, the laptop computer, and the DC-DC converter identified. The 10Base2 Ethernet is the black coaxial cable connecting the radio to the laptop.

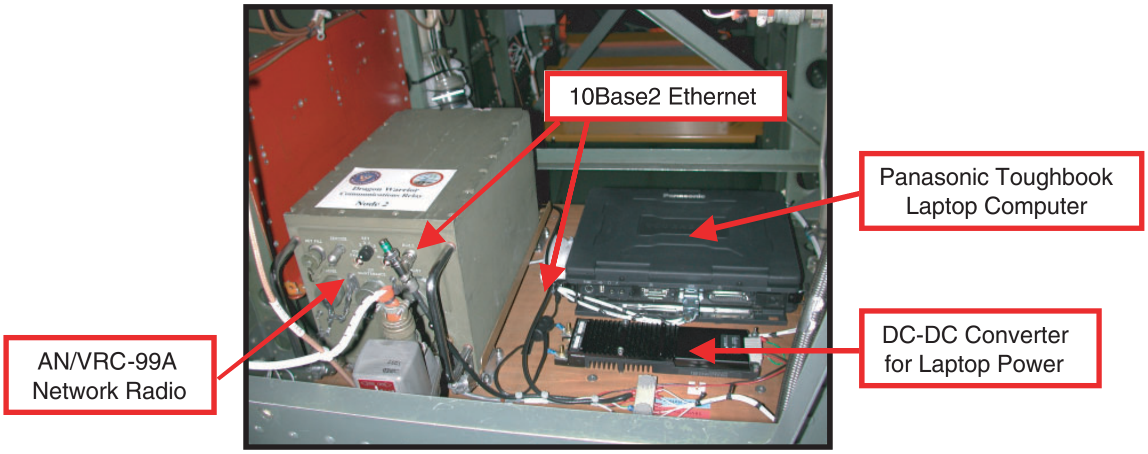

Fig. 4 — The Comm Relay payload bay contains the AN/VRC-99A radio,
Panasonic Toughbook Comm Relay controller, and DC-DC converter

Figure 5 shows the Kaman Aerospace K-MAX helicopter. The Comm Relay payload bay is identified, and the blade-type antenna is highlighted and shown in detail. This antenna design is specifically tailored for airborne use, with the aerodynamic radome protecting the antenna from damage at high aircraft speeds. Note that the antenna is mounted near the tail of the aircraft, and that portions of the fuselage are below the antenna location. This configuration can cause the antenna to be masked by the front portion of the vehicle. This is discussed later in the Results section this report.

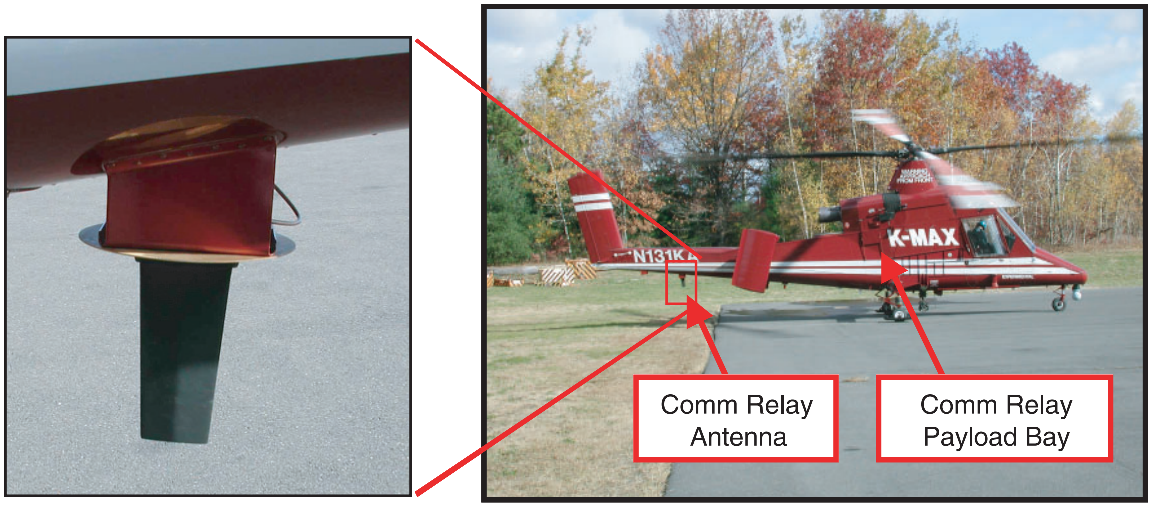

Fig. 5 — The K-MAX helicopter; inset shows the Comm Relay antenna and payload bay

Ground Station Equipment Configuration

The ground station included the network radio and Comm Relay controller, but it also required additional equipment because the 28 VDC required by the VRC-99A was not available on the ground vehicles. A portable generator provided 120 VAC for all of the ground station equipment. An Accopian 28VDC power supply powered the VRC-99A, and standard AC power adapters were used for the laptops. Any additional auxiliary systems could be connected to the ground station's LAN via a NetGear EN104 Ethernet hub. The radio antenna was connected directly to the VRC-99A and mounted on the ground vehicle roof via a magnetic mount and cable ties attached to the roof rack. Figure 6 is a system diagram for the ground units, and Fig. 7 shows one of the ground stations with the roof-mounted antenna and the generator mounted on a trailer-hitch cargo carrier.

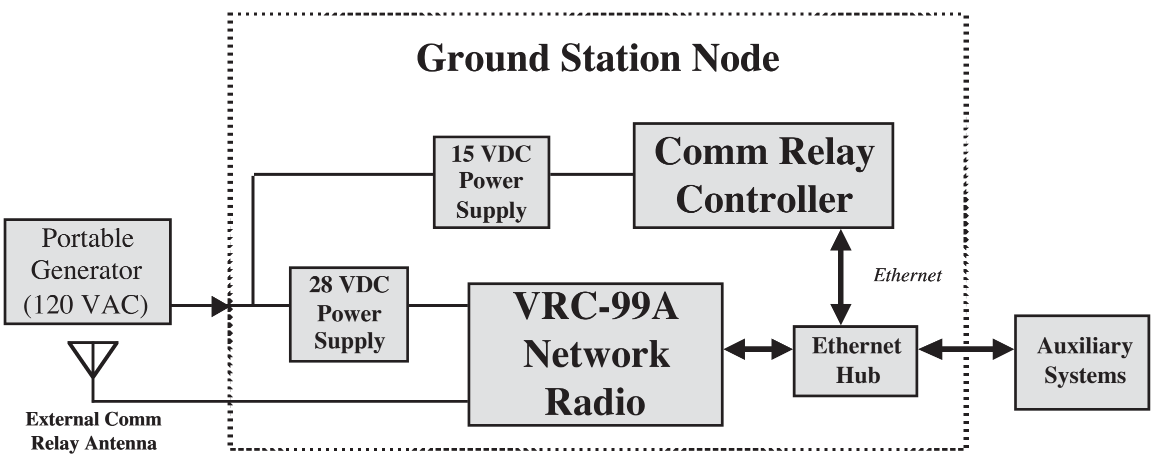

Fig. 6 — The ground station system requires additional equipment for power and auxiliary systems interfaces

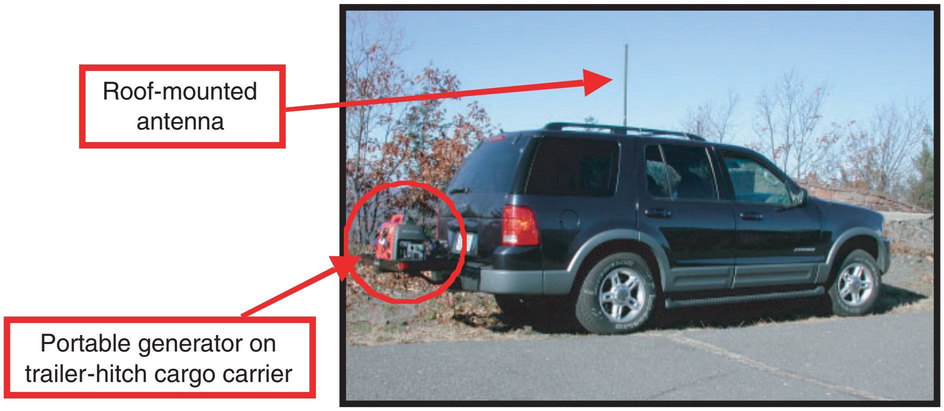

Fig. 7 — The ground station had a roof-mounted antenna and a portable generator mounted on a trailer-hitch cargo carrier to provide power

To provide maximum portability, a transit case with integral equipment rack was used for mounting all the ground station equipment. Figure 8 shows the equipment configuration with the locations of the radio, the power supply, and the laptop computer identified. The cabling for the laptop computer had sufficient slack to allow it to be used from the front seat of the vehicle with the equipment rack located in the rear.

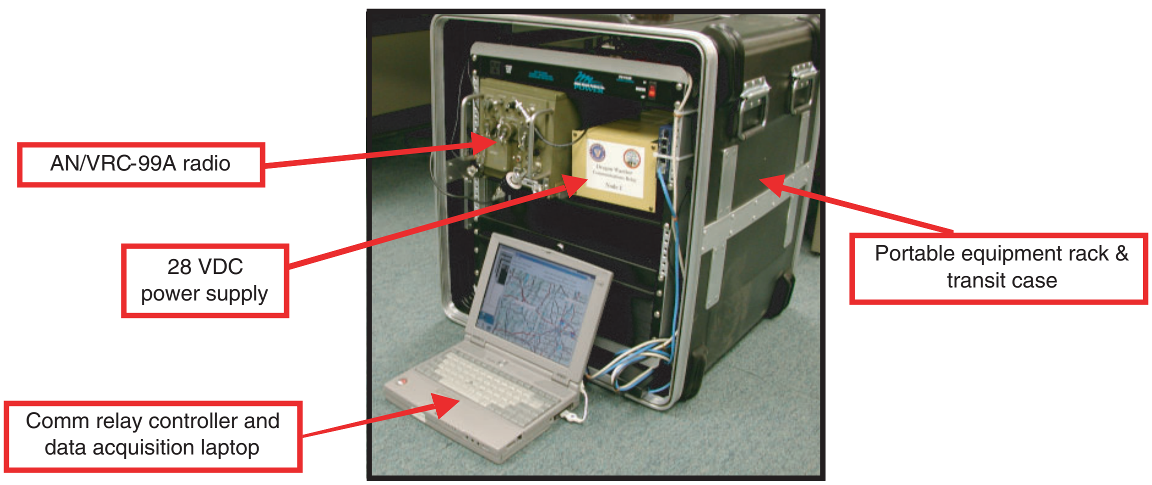

Fig. 8 — The ground station equipment, mounted in a portable transit case, included the AN/VRC-99A radio, the Comm Relay Controller laptop, and a power supply

Test Procedures

Test and Analysis Software

We used NRL's MGEN (Multi-Generator), a real-time scripted TCP/IP traffic generator to create data streams (called flows) from all three nodes. Each test generated six flow rates to create dynamic network traffic. MGEN generates time-stamped, sequenced packets with embedded real-time GPS information for each node. The ground stations received their GPS data from Motorola M12 GPS units, and the airborne unit received its GPS information from the remote management system (RMS). Under normal Dragon Warrior

operation, the airborne relay would not be a source of traffic, but for these tests we wanted a complete picture of traffic for all links, so the airborne node generated and recorded data just as the ground nodes did.

Received packet data were logged at all three nodes by DREC (Dynamic Receiver), NRL's TCP/IP traffic receiver/logger. DREC not only permits real-time display of the data for performance monitoring, but also records data for post processing analysis. Our real-time displays showed received data throughput, but other network performance parameters (such as packet loss or latency) can also be displayed or processed off-line. Each of the log files created by DREC represents the network activity as seen by the receiving node, and the entire test can be replayed from any node's perspective for post processing. Each node transmitted flows not only to the other two nodes, but also to itself. With this approach, each node's DREC log file stored the received traffic from the other nodes along with its own GPS data. The files contained location information not only for the remote nodes, but also for the local node, even when no network connectivity exists.

To display the network performance graphically, NRL's TRPR (Tcpdump Rate Plot Real Time) provided data filtering and formatting to create plots using GnuPlot. The plots showed data throughput as a function of time for all three flows being received at each node.

JMap, NRL's moving map application, provided a real-time display of the vehicle locations. The vehicle locations were shown with a cross-hair indicator and text label listing the node name with a background coloring scheme to show good (green), marginal (yellow), and lost (red) connectivity. A side-bar indicator showed the GPS fix status as either valid (green), or invalid (gray). Figure 9 is an example of the JMap display during one of the tests with the Dragon3 node showing marginal connectivity, and Dragon1 and Dragon2 nodes with good connectivity.

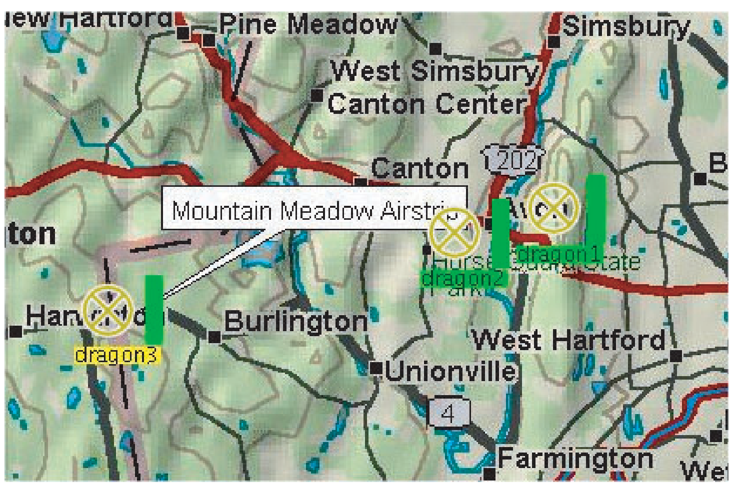

Fig. 9 — The JMap program displayed moving icons that showed the position of each vehicle, and provided a color-coded network status indicator

All of the software tools used for these tests are available for downloading from the following sites:

MGEN/DREC Toolset	http://manimac.itd.nrl.navy.mil/MGEN
TRPR	http://manimac.itd.nrl.navy.mil/Tools
JMap	http://pf.itd.nrl.navy.mil.

Network Configuration

When the Comm Relay is used operationally, each of the ground stations will be connected to its own LAN subnet, and the VRC-99A radio will serve as the router/gateway for each of those subnets. All of the tactical computer systems on the LAN (as represented by the Auxiliary Systems in Fig. 6) would be part of the subnet. The airborne subnet would have only the VRC-99A and the Comm Relay Controller as members, since no additional tactical computers would be on the DW aircraft. The VRC-99A radios also connect to an over-the-air (OTA) network that is separate from the other subnets. The radios belong to both the OTA subnet and the local LAN subnet, and function as the router between the two subnets.

Figure 10 is a functional diagram of the network configuration that was used for the tests. Subnet1 (with IP addresses 192.168.1.X) resided on Ground Station 1 and comprised *Dragon1* (the Comm Relay Controller laptop), the *Router1* Ethernet interface to the VRC-99A, and any ancillary equipment connected through the Ethernet hub. Subnet3 (with IP addresses 192.168.3.X) was similarly configured on Ground Station 3. Subnet2 (with IP addresses 192.168.2.X) had only *Dragon2* and *Router2* connected to the radio. The OTA interfaces on the radios (i.e., *OTA1*, *OTA2*, and *OTA3*) were members of the OTA subnet (with IP addresses 128.1.0.X). We used standard IP subnet masking; in our case, this means that no member of a subnet would operate in any other subnet without changing its IP address. All communication between the subnets was routed via the radios through the OTA subnet.

Radio Configuration

For our tests, the VRC-99A radios were used in the single-frequency mode at 1412 MHz, with an RF output power of 10 W. Of the 32 time-division multiple-access (TDMA) slots available, 8 were assigned to each of the ground stations, and 16 were assigned to the airborne node.

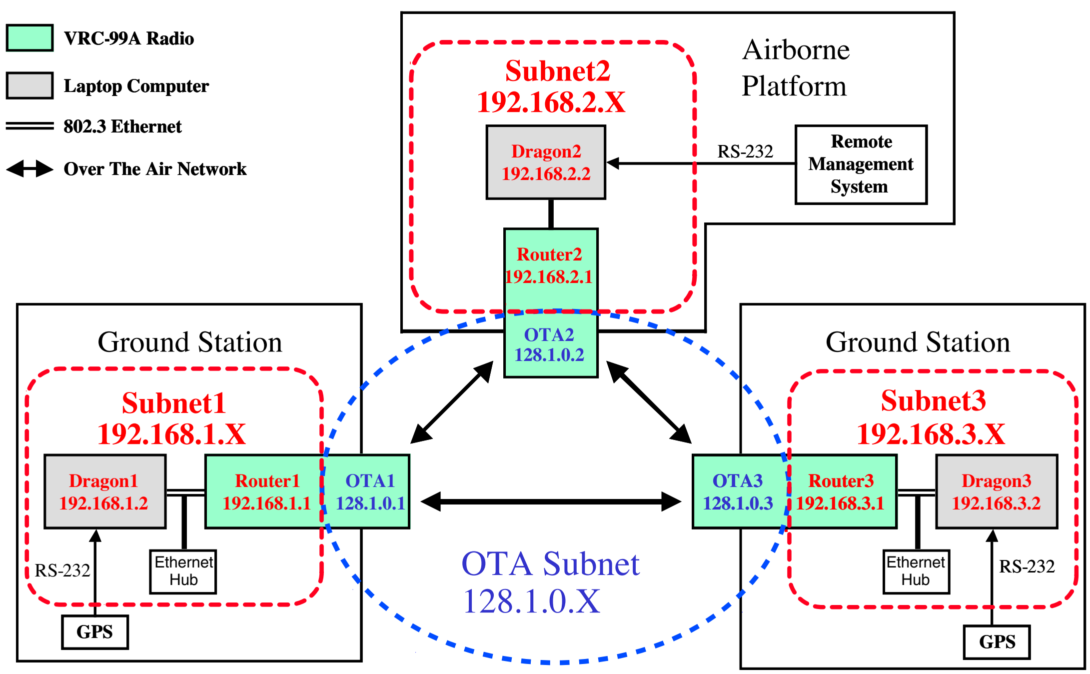

Fig. 10 — The network configuration for the test comprised two ground station subnets, an airborne subnet, and an over-the-air (OTA) subnet

Scripts

Each of the tests involved running multiple programs on all nodes; to simplify this process, scripts were written for each node. A common script was used to start each test, but the script was able to determine from which node it was executed, and ran the appropriate programs for each node. The MGEN and DREC programs were run on all nodes, but the flow designators were tailored to reflect the source and destination node numbers. TRPR, Gnuplot, and JMap did not run on the airborne unit, since there was no operator to view the displays. At the completion of each test, another script was executed to stop the test, which terminated the appropriate processes and copied the log file to an archive file.

Because of the variability of preflight preparation, locations of the ground stations, and flight times for the various sorties, the scripts on each node were not guaranteed to be started at exactly the same time. All scripts were started within several minutes of each other, and since the data included time stamps for all packets, registration of events with clock time was possible.

3. TEST RESULTS

Ground-to-Ground Test

The objective of this test was to determine usable range between ground vehicles with no airborne relay. The ground-to-ground test was performed near Kaman headquarters in Bloomfield, CT. The terrain in this area can be characterized as a hilly wooded suburban community. Clear line of sight between ground vehicles is difficult to obtain in this terrain, and blockage due to foliage and buildings is a major factor.

The test setup comprised one stationary vehicle with a second mobile vehicle following radial patterns emanating outward from the fixed node's position. Figure 11 shows the area of the tests, with the stationary vehicle positioned in the center, and flags positioned at locations where the signal was lost (when the mobile vehicle was moving away from the stationary vehicle), or where the signal was recovered (when moving toward the stationary vehicle). A circle with a 1-mi radius from the stationary node is drawn for reference.

The results of this test showed that the maximum achievable range was consistently less than 1-mi. Even though the radios were transmitting at 10 W, the foliage, terrain, and nearby buildings significantly blocked the VRC-99A's 1.4 GHz radio signals. Under these conditions, it is apparent that an airborne relay is necessary to provide connectivity between these radios, even at close range.

Short-Range Low-Altitude Test

While the aircraft was performing targeting and mapping tests for the EO/IR payload, we took the opportunity to collect communications data, even though the aircraft was not being operated at the Comm Relay mission altitude. The purpose of collecting data under these conditions was to determine the feasibility of using an airborne relay operating at low altitudes. While the aircraft was performing its targeting and mapping functions near the Mountain Meadow Airstrip, our mobile ground node drove along nearby roads to collect connectivity data. Figure 12 shows that under these conditions, the connectivity between the aircraft and the mobile unit (shown by the purple line) was very sparse compared to the actual path followed by the ground vehicle (shown by the green line). Connectivity was achieved for less than half of the time of the test. Nearby foliage and the hilly terrain of this area created significant blockage. Because of the relatively short distance to the aircraft (typically less than 10 mi), it was not difficult to predict when outages would occur as we proceeded along the roads between the hills. The signal would typically be recovered when the mobile unit moved into an area where it had a clear view of the sky in the direction of the aircraft.

Fig. 11 — The ground-to-ground tests were performed around a central stationary vehicle within a 1-mi radius (shown as a red circle)

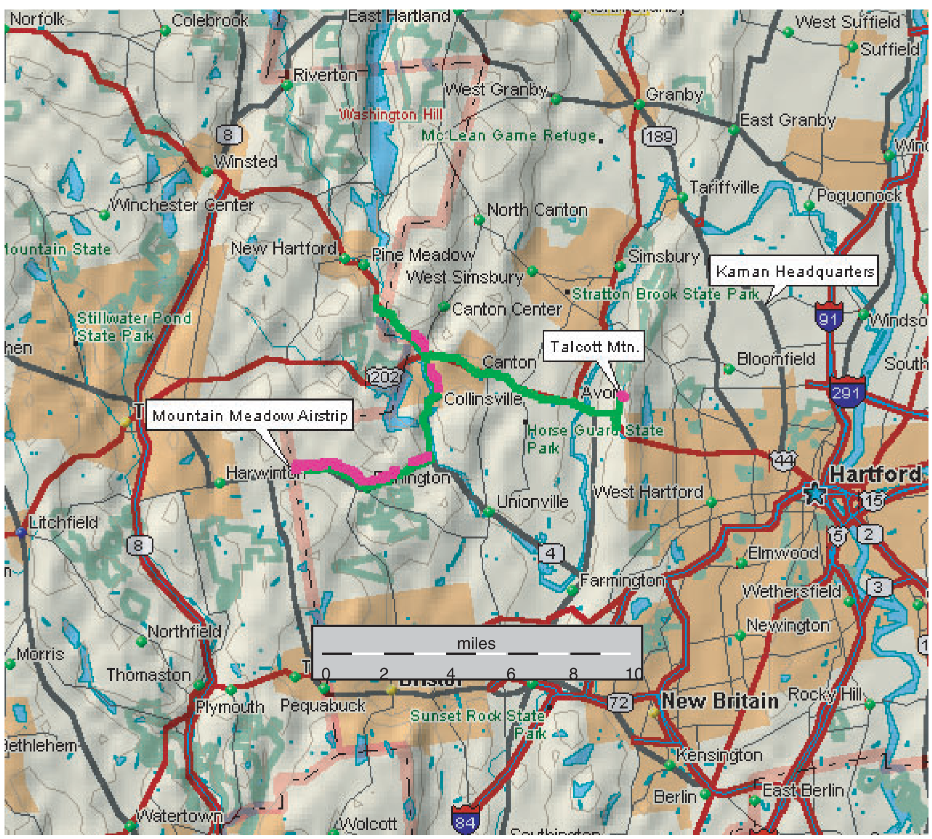

Fig. 12 — A comparison of the mobile ground vehicle actual path (green line) and the areas of connectivity to the aircraft (purple line) shows that foliage and terrain caused significant blockage when the K-MAX was operating below the Comm Relay mission altitude.

The conditions of this test were such that terrain caused significant blockage because the aircraft was usually not high enough to provide clear line of sight to the ground vehicle. The implication is that the low-altitude requirement for targeting missions is unsatisfactory for Comm Relay missions. Without sufficient altitude to provide clear line of sight (LOS) to the ground stations, the Comm Relay cannot provide adequate coverage in this type of terrain.

Long-Range Over-Seawater Test

The objective of this test is to collect performance measurements when the air vehicle is over seawater and the ground vehicles are located ashore. Multipath effects due to RF reflections from seawater are expected to contribute to performance differences. This test simulates the performance of the network when DW is launched from a Navy ship in support of Marines ashore.

The flight conditions were such that the aircraft was to maintain as close to the 6000-ft mission altitude whenever possible. Weather and FAA restrictions limited actual altitudes to 4500 to 5500 ft. The flight paths followed the two sorties described in Section 2. The ground stations were stationary on Talcott Mountain (890-ft elevation) and at Lighthouse Point (40-ft elevation) for Sortie 1, then on Talcott Mountain and at Short Beach (10-ft elevation) for Sortie 2. From these locations, the aircraft would reach a distance of more than 50 nmi over land from Talcott Mountain, and more than 50 nmi over water from Lighthouse Point and Short Beach.

Sortie 1

For the first sortie, the flight path (shown in Fig. 1) began at Kaman headquarters, went past Talcott Mountain, past Lighthouse Point, to Block Island, and returned by retracing the same path. Talcott Mountain provided a good "high ground" vantage point for maintaining long LOS over much of the terrain. Lighthouse Point provided a good vantage point over water to the south. However, as we discovered during this test, the view to the east (which is the direction the flight path followed) was obscured by a nearby tree line. Figure 13 shows the connectivity between the K-MAX aircraft and the ground station at Talcott Mountain as a yellow line, and connectivity between the K-MAX and the ground station at Lighthouse Point is shown in purple. Areas where the yellow and purple lines are adjacent to each other is where the airborne node functions as a relay between the two ground stations.

The figure shows that as the K-MAX proceeded from Kaman headquarters toward Lighthouse Point, the Talcott Mountain ground station had good connectivity but the Lighthouse Point location was masked by the terrain to its north. As the K-MAX reached the area approximately 15 miles north of Lighthouse Point, the ground station there began to communicate with the K-MAX and a relay was established (at position (1)). As the K-MAX approached the area near Lighthouse Point, it descended to 1500 ft, at which time LOS and connectivity to Talcott Mountain was lost. After passing Lighthouse Point, the K-MAX turned east to begin its overwater path along Long Island Sound and resumed its planned flight altitude, which restored the connectivity to Talcott Mountain (at position (2)). Lighthouse Point maintained connectivity to the aircraft until it was 34 mi away (at position (3)), at which time the local tree line at Lighthouse Point obscured its LOS. Connectivity to Talcott Mountain was intermittent for the remainder of the outbound flight because of the local mountains and ridge lines between Talcott Mountain and Long Island Sound. The local mountains obscured portions of the flight path from the Talcott Mountain location because, although the K-MAX was 4000 to 5000 ft high, at the maximum range of 65 mi (at location (4)) the direct LOS to the aircraft was less than one degree above the horizon.

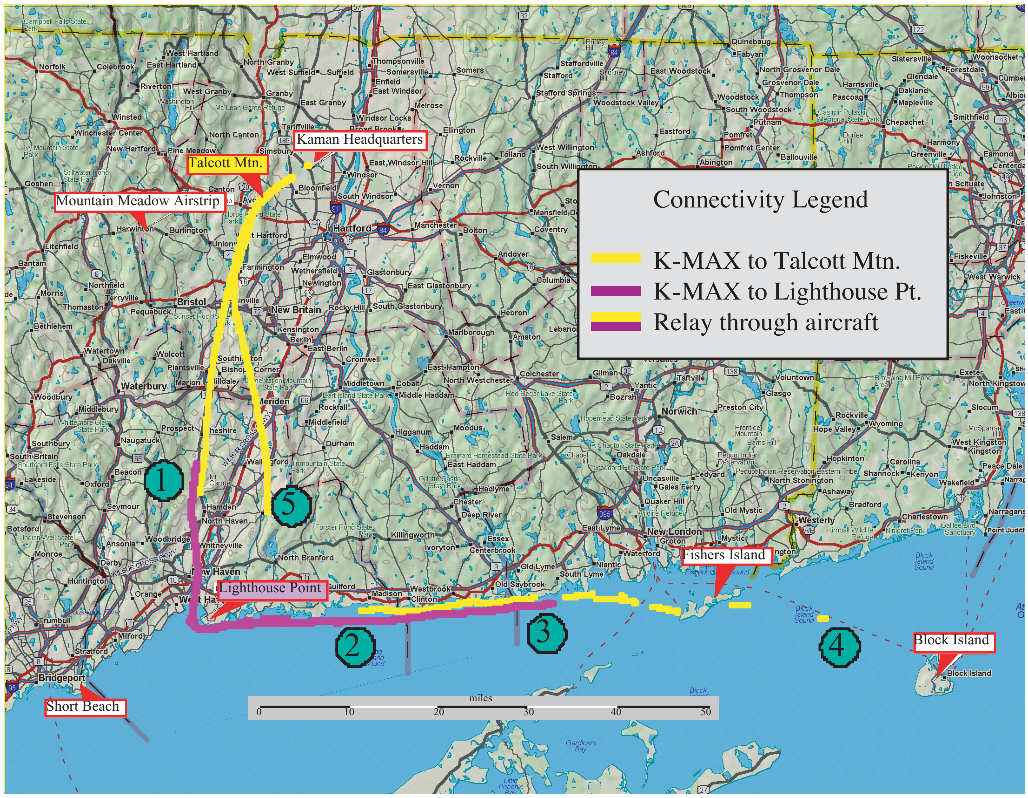

Fig. 13 — Connectivity between the K-MAX and the two ground stations during Sortie 1 shows the masking effects of the terrain

On the return leg, the Lighthouse Point location did not regain connectivity with the K-MAX, apparently because the fuselage masked the antenna on the aircraft. The K-MAX was flying into the wind for this leg, causing it to assume a nose-down attitude, further contributing to the masking problem. At location (5), Talcott Mountain regained connectivity to the K-MAX and maintained it until the end of the flight.

Because of the lack of good LOS over 50 nmi of water from the Lighthouse Point location, the ground station was moved to Short Beach for the second sortie.

Sortie 2

For the second sortie, the flight path (see Fig. 1) began at Kaman headquarters, went past Talcott Mountain, to the vicinity of Short Beach, to Fishers Island, and returned by retracing the same path. Figure 14 shows the connectivity between the K-MAX aircraft and the ground stations for Sortie 2.

The second sortie provided some results that were consistent with the results of the first sortie, and some results that were improvements in performance. As with the first sortie, good connectivity was quickly established and maintained with the Talcott Mountain ground station. For this sortie, however, the K-MAX maintained high enough altitude to serve as a good relay to the Short Beach location (at (1)). When the aircraft started traveling eastward, connectivity was intermittent to Talcott Mountain but consistently was reliable to Short Beach (at (2)). Signal blockage by the mountains between Long Island Sound and Talcott Mountain were the major cause of drop-outs to that ground station. The Short Beach ground station had good connectivity, with only occasional breaks until the aircraft began its return path near Fishers Island (at (3)). Note that as the K-MAX began its return trip, it was communicating with both Talcott Mountain (at a

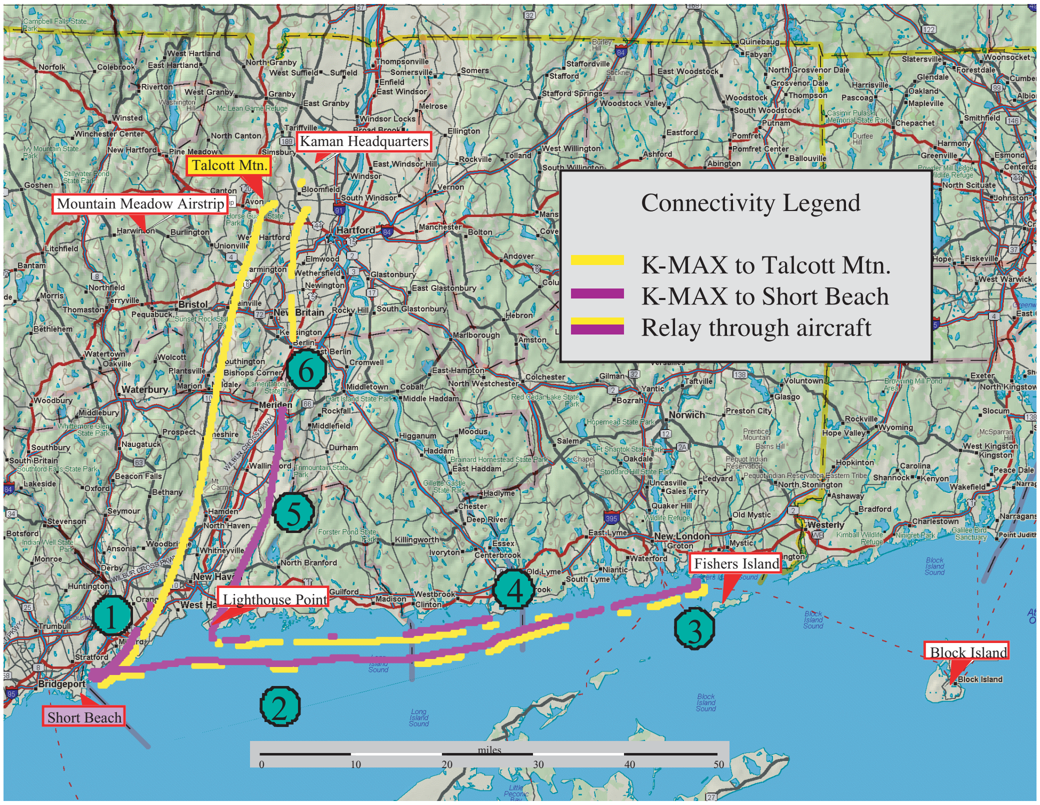

Fig. 14 — Connectivity between the K-MAX and the two ground stations during Sortie 2 shows the masking effects of the terrain and the aircraft fuselage

distance of 55 mi) and Short Beach (at a distance of 60 mi) and functioning as a relay between the two. This shows that with good LOS, the Comm Relay will be able to meet the target range requirements.

As soon as the K-MAX began its return trip, it again assumed a nose-down attitude to compensate for head winds. This again caused the antenna on the tail of the aircraft to be masked by the fuselage from both ground stations. The long range to the aircraft weakened the signal, which also contributed to the drop-out. On the return trip, the K-MAX altitude was increased to 5500 ft, which contributed to the signal being recovered (at (4)) by both ground stations, although antenna masking was still evident from the Short Beach location.

As the K-MAX turned northward, the antenna was no longer masked from the Short Beach location and connectivity was restored, but the Talcott Mountain location was now masked. This condition continued until the terrain blocked the LOS from Short Beach, causing loss of connectivity (at (6)). Shortly afterward, the K-MAX was close enough to Talcott Mountain to overcome the masking, and connectivity was maintained for most of the remainder of the test.

Network Throughput Measurements

Data throughput vs time plots were displayed to monitor the behavior of the network. Figure 15 shows the throughput plot for data received at the Talcott Mountain ground station. The red trace is the data from Talcott Mountain, the green trace is data from the K-MAX, and the blue trace is data from the Short Beach location. The dotted lines show the data rates that are actually transmitted at the source. The red trace on this figure represents locally generated data that are not transmitted by the radio.

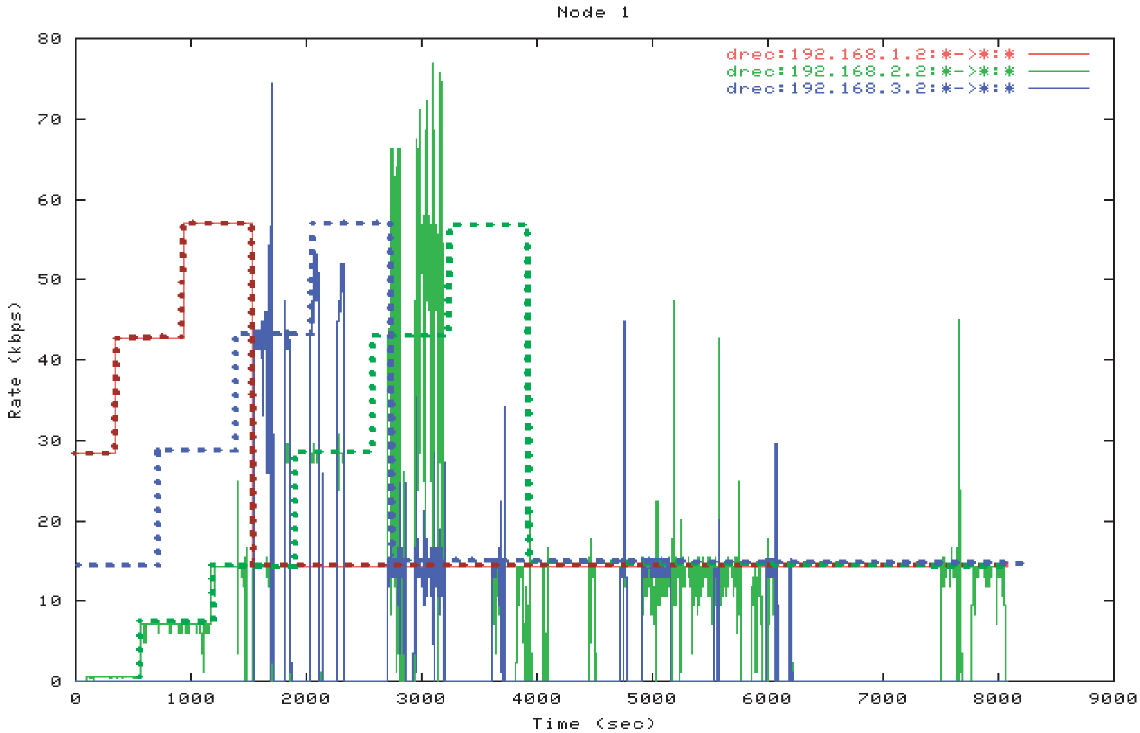

Fig. 15(a) — Throughput measurements for data received at Talcott Mountain shows the intermittent connectivity to both the airborne node (green) and the other ground node (blue)

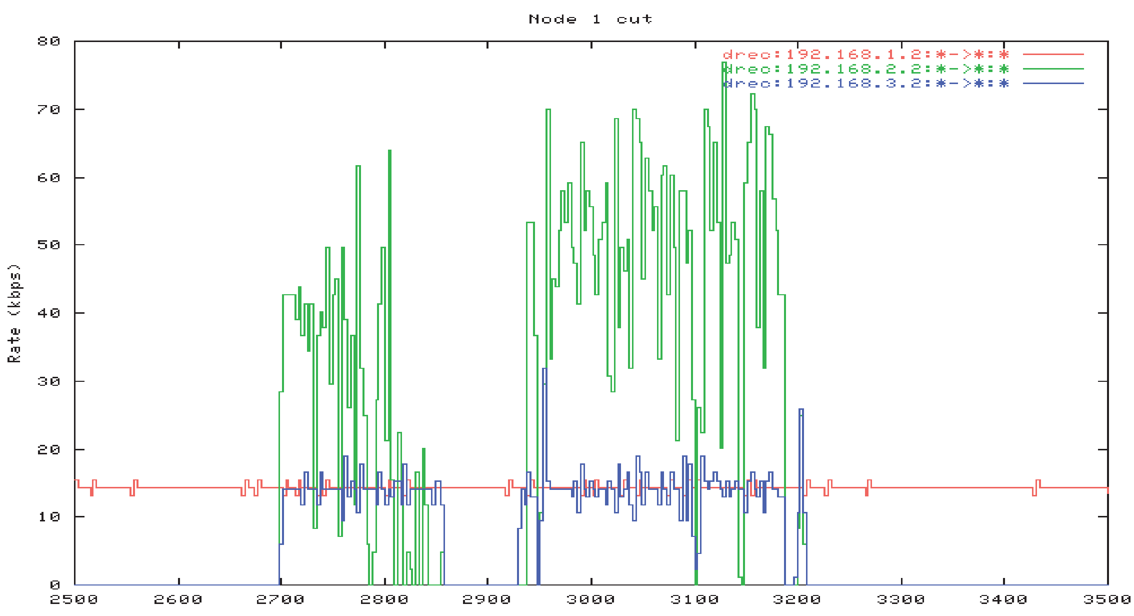

Fig. 15(b) — A close-up of the throughput measurements shows details of the variation in network traffic

The figure shows that there were some periods of good connectivity (such as where a solid line closely follows the corresponding dotted line), some periods of marginal connectivity (where the solid line varies significantly from the dotted line), and periods of no connectivity (where the solid line is zero). The variations in the solid line, which seem to indicate that the data are being received faster than they are being transmitted, are caused by the buffering mechanism in the radio. When transmission errors occur, the radio repeats the transmission in a best-effort attempt to provide reliable data transfers. The radio buffers the data until either the data are received or the buffer overflows, at which point some data are discarded. When the radio transmits a large amount of data that is stored in its buffer, the instantaneous data rate can actually exceed the data rate being generated by the source alone. For UDP packets (which is the protocol we used for this test), a buffer overflow condition causes the packets to be simply dropped. For TCP packets (the guaranteed delivery protocol used for most Internet connections), an error condition is sent to the application program. For our tests, we chose to use UDP packets to prevent excessive buffer overflow and time-out errors that are likely to occur with TCP packets in this environment. The number of lost packets is one of the metrics that can be retrieved from the DREC log files for post-analysis.

Another feature of the plot that is not obvious is the fact that the blue trace is only nonzero when the green trace is nonzero. This is because Talcott Mountain did not have direct connectivity to Short Beach (blue), and could only receive Short Beach data through the K-MAX relay (green). The converse were not true, however. The green trace is nonzero in some areas where the blue trace is zero. This is because the data were being received from the K-MAX, but the network relay function has been temporarily suspended because of the loss of the link to Short Beach.

Figure 16 shows the same data from the perspective of the Short Beach ground station. On this figure, the local data are now the blue trace, and the remote ground station data are the red trace. This figure shows the same general behavior as the previous figure, but the buffering mechanism is even more evident. Note that there are more spikes in the data rate above 80 kbps and a few above 100 kbps. This indicates that the channel has intermittent drop-outs, but the drop-outs are not sufficient in length to cause packets to be discarded. The buffer is more nearly full, and quick bursts of large amounts of data manifest themselves as high throughput values. Also note that now the red trace is only nonzero when the green trace is nonzero, for the same reason that was described earlier.

AN/VRC-99A Radio Operation

The VRC-99A radio is designed to provide backbone network service for networks of up to 16 radios. Although our network contained only three radios, the delays in start-up time and recovery of loss of signal were excessively long, and may be problematic when trying to use these units in field exercises. During our tests, we often questioned whether the radios were functioning properly based on what we observed on the front panel indicators and what we saw in our test software. It was typical for the receive indicator on the front panel of the radio to begin blinking up to a minute before network connectivity was achieved. Under conditions where connectivity was intermittent, the receive indicator would blink for a short time then stop, without ever regaining connectivity to the network.

We performed some basic bench tests to get some quantitative measurements on start-up times, signal loss, and recovery timing. From power-up, it took approximately three minutes for the radio to begin processing network traffic. We found that for any loss of signal (10 dB below the radio sensitivity) for more than 15 seconds, it takes 50 to 60 seconds for the VRC-99A to resume normal network traffic. Delays this long would be unacceptable for Marine Corps use during very mobile operations that might require intermittent loss of LOS to the Comm Relay.

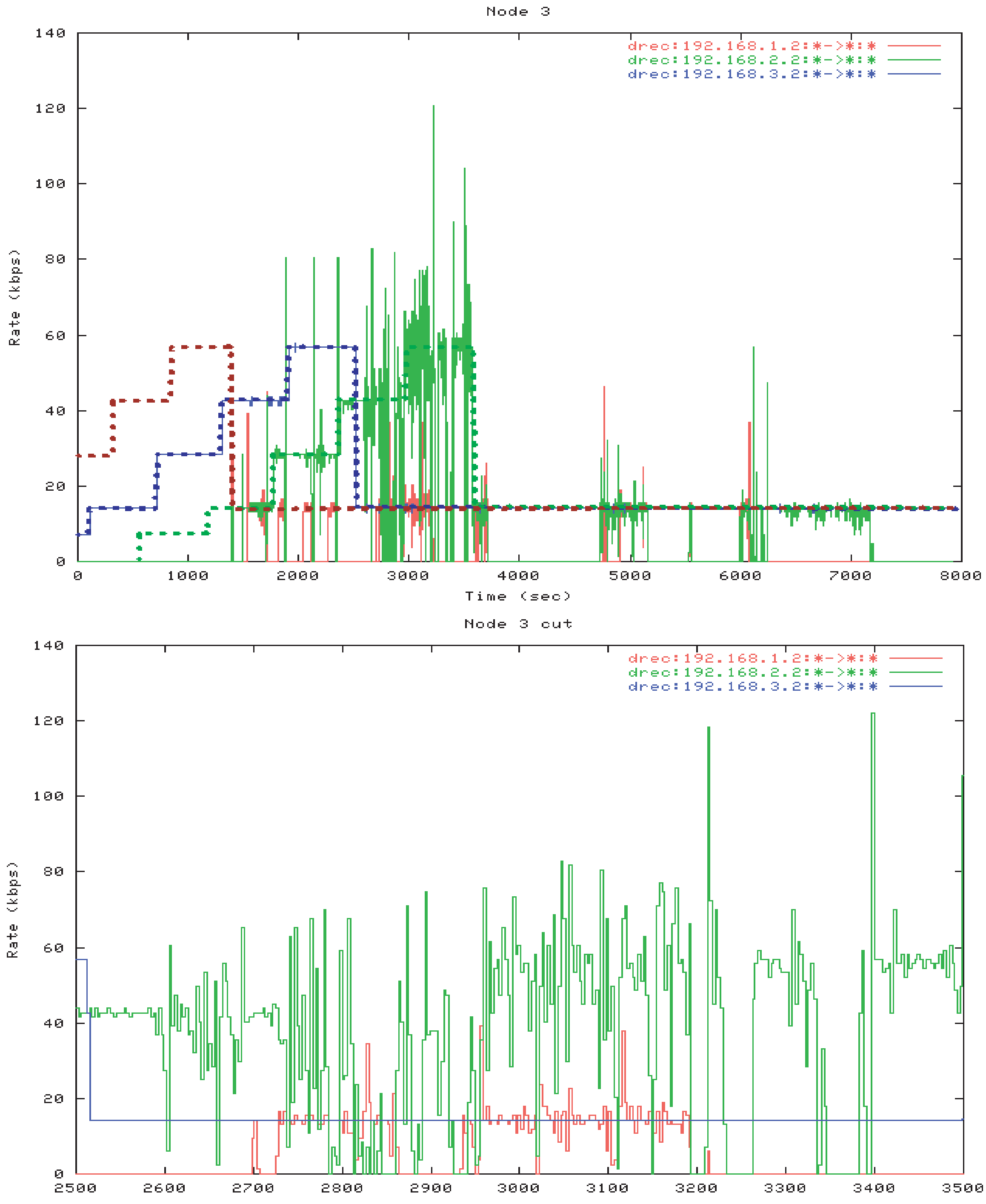

Fig. 16 — Throughput measurements show a different network behavior for data received at the Short Beach ground station

BAE Systems was contacted regarding this apparent problem with the VRC-99A. The start-up time includes the built-in test (BIT) time of approximately two minutes, and a Listen Mode time of approximately one minute. During the Listen Mode, the radio waits to receive data from other radios to determine its TDMA timing. If no other radios are detected, it begins transmitting to initiate network traffic. Once the network is established, the radio should not enter Listen Mode again unless it receives no signal for at least five minutes. Any shorter loss of signal should be recovered from in less than 10 seconds.

Our radios seem to enter the Listen Mode after only 15 seconds of lost signal. BAE has indicated that this is not the expected behavior of these radios, and further analysis of the problem is necessary. The software version of our radios (V1.0) is not the most recent (V1.2), but that was not identified as the source of the problem. As of the date of this report, they have not provided a solution, and this issue remains unresolved.

4. CONCLUSIONS

We can draw several conclusions from these tests. First, the VRC-99A requires clear line-of-sight to operate, even for relatively short distances. Both the ground-to-ground test and the low-altitude test confirmed this. Significant signal blockage due to terrain, foliage, and buildings was observed, and avoiding these obstacles is an important operational consideration. This is typical behavior for radios operating in the L-Band (and higher) frequency range. Maintaining the Comm Relay mission altitude of 6000 ft (or higher) is important for providing good LOS.

Another important conclusion is that the target Comm Relay range of 50 nmi from the aircraft is achievable at the 6000-ft mission altitude, both over land and over seawater. During our long-range test, two ground stations separated by 48 mi were able to relay through the airborne node, which was 55 to 60 mi from both of them. Supporting ground units with a Comm Relay located 50 mi away can provide a significant tactical advantage. One of our secondary objectives was to determine whether multipath over seawater would adversely affect performance. However, we had no method to measure it directly, and we saw no evidence of it in our data.

Antenna masking by the air vehicle fuselage was significant during our tests, but this problem was specific to the particular air vehicle that was being used and where the antenna was located. On the K-MAX, the antenna was located aft of the fuselage and the aircraft assumed a nose-down attitude while flying. These combined to create significant masking when viewed from the front of the vehicle. This effect is expected to be negligible on the Dragon Warrior vehicle because it is designed to fly level, and the antenna will be located on the lowest part of the vehicle (excluding the landing gear). We will investigate antenna masking in our analysis and design of the antenna system for the DW prototype.

Operational use of the VRC-99A proved to be more complicated than we expected. It may prove to be unacceptable for the kind of mobile operations in which the Marine Corps would need them. Start-up and signal acquisition times were unreasonably long for the kind of dynamic environment in which they would be used. Observing the front panel indicators provided little help in determining the status of the network traffic, and at times the indicators were misleading. We will continue to work with BAE Systems to correct the problems and upgrade the software in the radio to provide the kind of quick response and transparent functionality that a high-data-rate network radio should have.

5. FOLLOW-ON EFFORTS

Since the conclusions of these tests, improvements have been made to the operational characteristics of the radio and to the methods of performing configuration management.

Radio Performance Improvements

The VRC-99A is a major component of the JTF WARNet program, and extensive laboratory and field testing has uncovered additional areas of improvement for the radio. The WARNet program is the conduit through which the VRC-99A will be transitioned from a developmental prototype to a deployed joint network communications asset.

The problems that we experienced with long recovery times after loss of signal have been corrected in later versions of the radio firmware. The link quality filter controls the rate at which the radios loses or reestablishes links. The original design used fixed parameters based on early system design specifications that are now obsolete. The new firmware not only allows the filter parameters to be changed, but the new default settings provide much better performance for a highly mobile user environment. Delays seen during our tests of typically one minute are now reduced to about ten seconds with the new parameters.

JTF WARNet has initiated improvements to radio functions that were not exercised in our test. The size and complexity of the WARNet architecture has led to additional performance enhancements. These enhancements include link quality filter improvements, adaptive slot allocation, improved OSPF performance, IP bridging, and quality of service (QOS).

Configuration Management Improvements

We have made changes to the Comm Relay Controller (CRC) to allow configuration management to be handled through a Web browser, thereby making the user interface platform-independent. Users with JavaScript-enabled browsers such as Netscape, Opera, or Internet Explorer can access the CRC from their PC, Macintosh, or Linux computer.

The new CRC hardware is a 5X86 133 MHz embedded Linux processor in a PC-104 form factor that runs a Web server with pages for checking radio status, creating, modifying, and uploading configuration files, and configuring the radio. The Web pages can be accessed from anywhere on the network through simple password-protected access controls. Special attention has been taken to eliminate the need for users to know the specific syntax required by the radio interface. Anyone with a general understanding of the operation of the radio and the configuration of the network to which it is connected will have no difficulty using the Web pages. Figure 17 shows a portion of the page that allows the user to create a configuration file. It uses familiar graphical interface controls such as check boxes, pull-down lists, and text areas for entering the radio parameters. Configuration checking functions display alerts for invalid conditions, thereby preventing the user from unknowingly entering conflicting parameters. Multiple configuration files can be created or uploaded to support multiple missions, frequency management restrictions, or test scenarios.

The JTF WARNet program is also adapting a Web-based configuration management approach. Their Systems Management Web Server will also include a database to maintain configuration and status information for all the radios in the joint network, to support their more extensive and detailed network management and monitoring requirements.

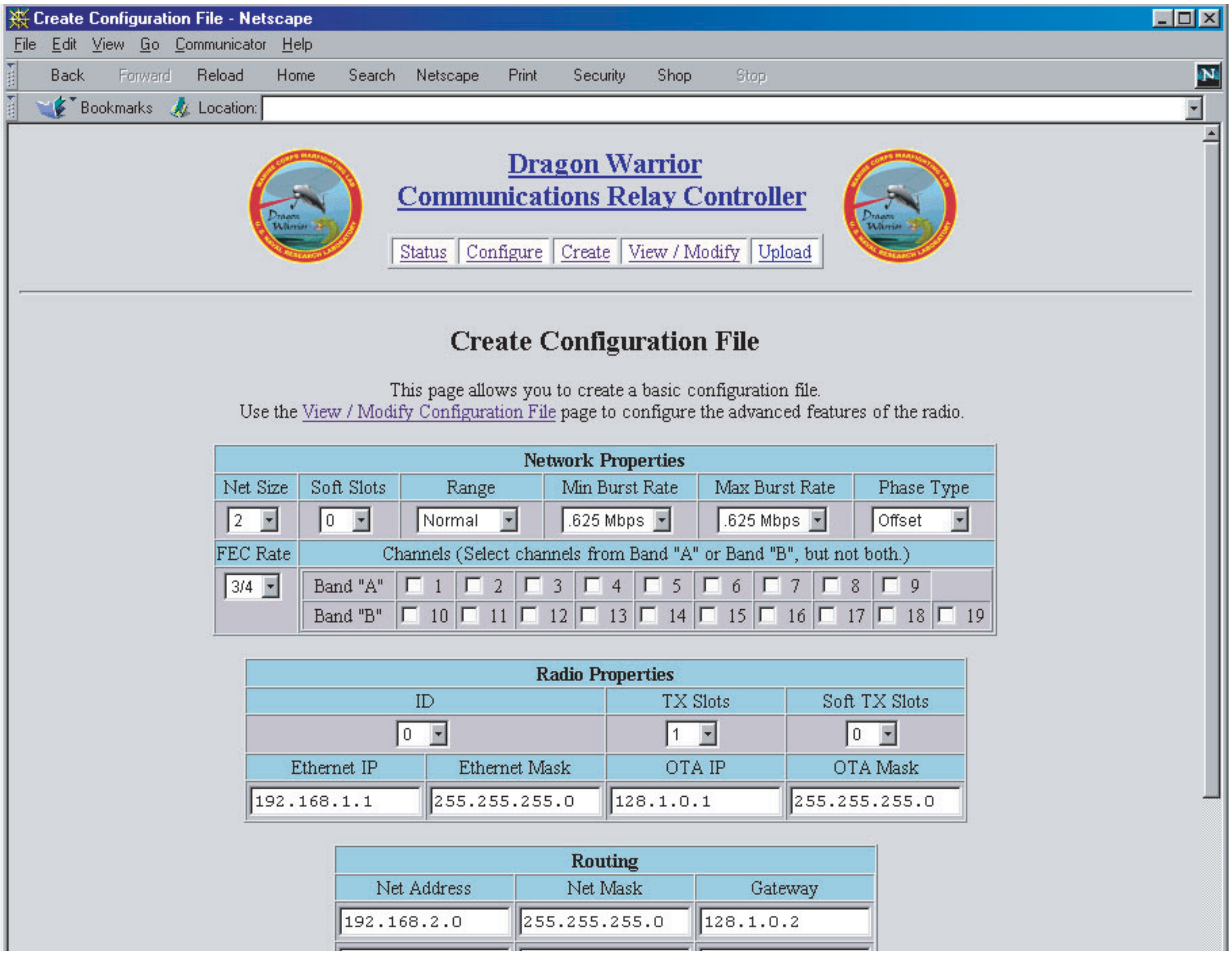

Fig. 17 — The CRC Web server provides configuration management through pages such as this "Create Configuration File" page

Comm Relay Payload

The Comm Relay Payload nose cone has been built and tested in the laboratory. Figure 18 is a sketch of the Comm Relay components comprising the VRC-99A, Comm Relay Controller, and antenna. The additional Inertial Navigation System and compass components are required by the aircraft avionics. Initial flight demonstration of the aircraft is scheduled for November 2002.

Field Testing

The Comm Relay Payload development will continue through FY03, with an emphasis on field testing. Testing will be performed at NRL's test flight facilities and, as required, as part of upcoming military exercises. Current plans include the first demonstration of the Comm Relay in a military exercise as part of the JTF WARNet Predeployment Exercise (PDX).

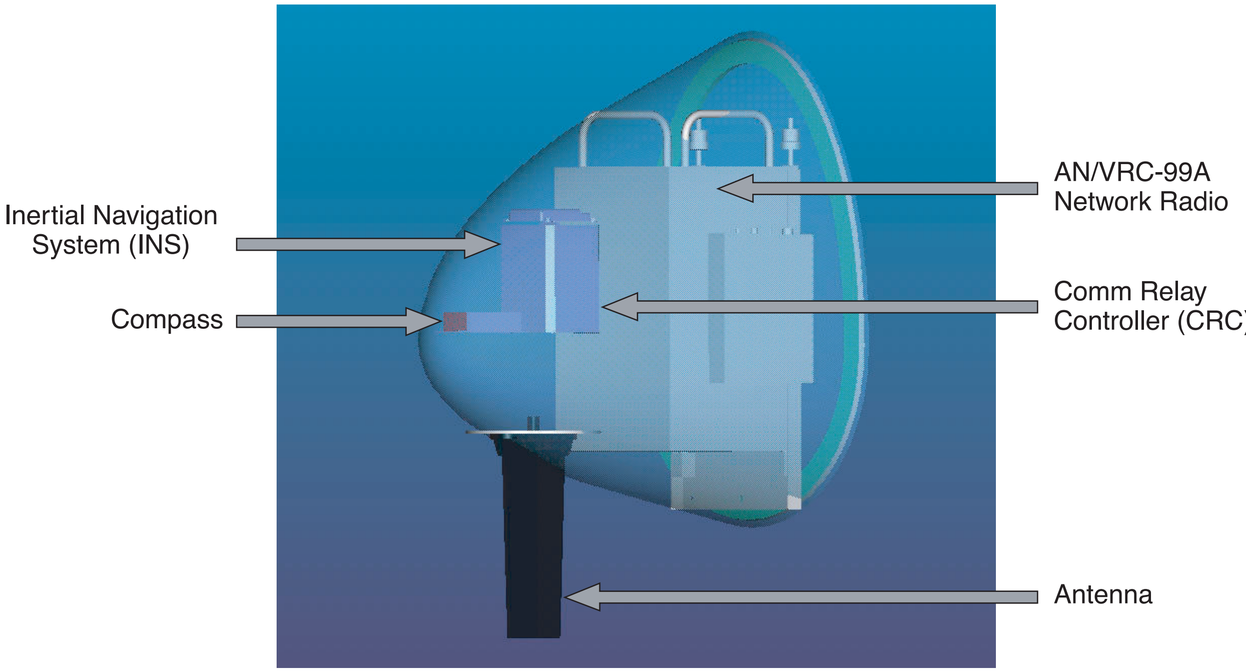

Fig. 18 — The Comm Relay Payload is a modular, replaceable nose cone for the Dragon Warrior unmanned air vehicle

6. SUMMARY

These tests have proven to be an overall success in that we have accomplished our goals and learned some important lessons about the network radios and the expected performance of the Dragon Warrior Communications Relay. Close coordination with the JTF WARNet program has provided important performance information. This information has contributed to improvements in the radio that will benefit the joint military forces. Field tests will be conducted to confirm that the Dragon Warrior Communications Relay will provide the type of networked data communications required by tomorrow's warfighters.

Appendix

EQUIPMENT PHYSICAL SPECIFICATIONS AND INTERFACES

Network Radio:	BAE Systems VRC-99A (3 each, 2 ground, 1 airborne)
Airborne Antenna:	Trivec Avant AV237-8 (1 each)
Ground Vehicle Antenna:	Antenna Products DPV-49N (2 each)
Airborne Comms Host:	Hewlett Packard Toughbook 27 (1 each)
Ground Comms Host:	Toshiba Satellite Pro 470CDT (2 each)
Ethernet Hub:	Netgear EN104NA (2 each)
DC-DC Converter:	VICOR MI-LC22-IW (1 each)

Network Radio

Type:	BAE Systems VRC-99A
Primary Power:	28 VDC, 140 W
Weight:	30 lb
Size:	3/4 ATR Short, 7.62-in. H × 7.5-in. W × 12.62-in. D (w/o handles)
802.3 port:	Ethernet 10Base2 BNC
Antenna Port:	Type N
Frequencies:	1308-1484 MHz, 2 bands, 19 channels, 8 MHz BW per channel
Output Power:	10 W maximum
Modulation:	Direct sequence spread spectrum, 20 Mcps, half duplex
Channel Access:	32 slot TDMA, 16 users, static allocation
Data Rates:	0.625, 1.25, 2.5, 5, and 10 Mbps
Throughput:	8.5, 14.9, 40.8, 92.5, and 195.9 kbps per TDMA slot (max.)
COMSEC:	Type 1 Cryptography available (Crypto Bypass Modules were used for these tests and equipment was UNCLASSIFIED)

Airborne Antenna

Type:	Trivec Avant AV237-8
Input Port:	Type N

Ground Vehicle Antenna

Type:	Antenna Products DPV-49N
Input Port:	Type N

Airborne Comm Relay Controller

Type:	Toshiba Satellite Pro 470CDT
Primary Power:	15 VDC, 3 A
Weight:	7.75 lb
Size:	9.5-in. L × 12.0-in. W × 2.5-in. H

Ground Station Comm Relay Controller

Type:	Toshiba Satellite Pro 470CDT
Primary Power:	15 VDC, 3 A
Weight:	7.75 lb
Size:	9.5-in. L × 12.0-in. W × 2.5-in. H

Ethernet Hub

Type:	Netgear EN104NA
Primary Power:	7.5 VDC, 1 A
Weight:	0.74 lb
Size:	4.0-in. L × 3.7-in. W × 1.1-in. H
10Base2 port:	BNC
10BaseT ports:	RJ-45 (4 ea.)

DC-DC Converter

Type:	Automated Business Power ABP-36V/ADJ/20A
Input:	28 V DC (from generator)
Output:	12 V DC (for Airborne Host, and Ethernet Hub)
Weight:	1.4 lb
Size:	4.5-in. L × 3.5-in. W × 2.1-in. H